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ILLUMINATING ENGINEERING SOCIETY

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VOLUME 22
No. 6 — 1957

32 VICTORIA ST
LONDON, SW1

Annual Subscription to Non-Members - £2.2.0
Price per Number to Non-Members - 5s. 0d.

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Automobile Headlamps

The I.S.O.-C.I.E. International Tests and their Influence on Meeting Beam Design

By J. H. NELSON, Ph.D., A.Inst.P., A.M.I.Mech.E. (*Fellow*)

Summary

The specification of the headlamp meeting beam has been a matter of disagreement between lighting engineers, in Europe on the one hand, and in the United Kingdom and the United States on the other, for many years.

Although the setting up of a Joint Working Party to study the question by the International Standards Organisation (I.S.O.) and International Commission on Illumination (C.I.E.) has not resolved these differences, the report[1] submitted by the Working Party to the C.I.E. in Zurich in 1955, and to the I.S.O. in London in 1956, records, for the first time, an attempt by each side to understand the ideas and problems of the other, and registers complete unanimity on the overwhelming importance of the correct use and maintenance of car headlamps.

The purpose of this paper is to describe the background against which these tests were carried out, and the nature of the results. The Working Party's recommendations are discussed and the adoption of an asymmetric beam, hitherto the distinguishing characteristic of Anglo-American practice, as the new unified European beam is noted.

Two Systems of Meeting Beam Design

Since the beginning of the motoring era vehicles have been more or less freely imported, not only by countries without an automobile industry, but also by countries making their own cars. The requirements of the home market have almost invariably dominated the design of vehicles, and each of the major manufacturing countries contributed engineering features which necessity required in their own countries, and which were appreciated in others.

Strictly engineering features can always be examined and appreciated by a driver, particularly an enthusiast, without relation to other road users and merely as a matter between himself and his motor car. This, however, is not true of all aspects of the design of the motor car and, particularly, the efficacy of the headlamp meeting beam cannot be assessed except in the presence of another vehicle similarly equipped, and judgment can only be passed on it when it is used in traffic and in the natural situations that are bound to occur in ordinary life.

Whilst the number of motor cars interchanged between countries supporting the European school of thought and those supporting the Anglo-American school remained relatively small, the foreign lamps fitted on the imported car were looked upon as harmless eccentricities and were discarded for the superior home-made product. The lighting engineers tended to accept this attitude and dismissed work and developments that did not take place within their own spheres as of very little importance.

The post-war demand for vehicles throughout the world necessitated a different approach to the problem. The very large number of vehicles sent into Europe by the British and American automobile industries after the war caused the European authorities to start a chain of enquiries which culminated in the setting up jointly by the I.S.O. and the C.I.E. of a working party to compare the efficacy of lamps made to the European ideas with those made to the Anglo-American ideas, and the I.S.O. undertook to report these findings to the Economic Commission for Europe. At the

The author is with Joseph Lucas Ltd. The manuscript of the paper was first received on October 11, 1956, and in revised form on November 13, 1956. The paper was presented at a meeting of the Society held in London on December 11, 1956.

same time, manufacturers who were exporting a far higher percentage of their production than before the war found it necessary to consider the legal requirements of the countries of their foreign customers far more seriously than hitherto. In particular, British manufacturers became involved, since Britain was exporting over half the cars produced and these cars were distributed to all markets.

In the case of the headlamp meeting beam, British manufacturers found it necessary to comply with different legal requirements, in the United States and Canada on the one hand, and in Europe and its dependencies on the other. This was, of course, in addition to the requirements of the British Commonwealth with the left-hand rule of the road. Thus, the British lighting engineer became not only a participant of his own school of thought, but an active designer in both schools of thought.

European Meeting Beam

The meeting beam characteristic of the European school of thought was one with a hard horizontal cut-off just below the horizontal plane, and with a completely symmetrical distribution about the vertical plane. The almost optical cut-off below the horizontal plane led to very low glare intensities and a high degree of comfort. The means for obtaining the beam distribution as well as the photometric requirements of the beam itself were specified, though there were certain differences between the European countries.

Essentially, the meeting beam design depended upon the use of a specially shielded filament. Fig. 1 illustrates the arrangement of the main and meeting beam filaments, whilst Fig. 2 shows diagrammatically the formation of the meeting beam by the combination of the parabolic reflector and the specially shielded filament. The

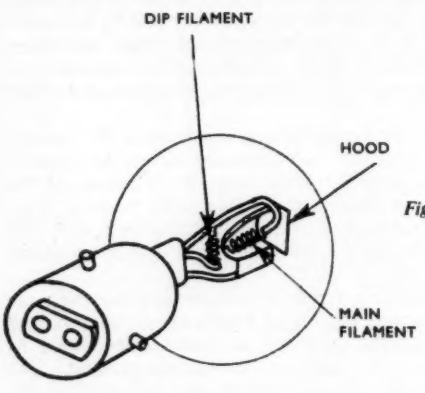

Fig. 1. European bulb filament arrangement.

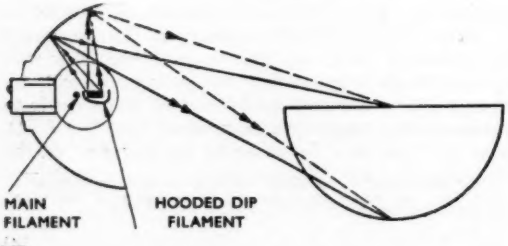

Fig. 2. Formation of Europe meeting beam.

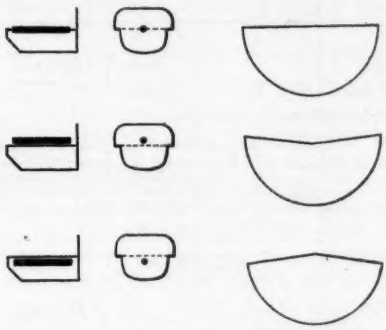

Fig. 3. Effect of movement of filament in shield.

diagram shows the formation of the beam shaped like a " D " on its side; the horizontal cut-off is, of course, a distorted real image of the metallic shield placed near the filament, so the relationship between the filament and its shield must be held very accurately if the resulting beam is to be consistent. The effect of a simple up and down motion of the filament relatively to its shield being shown in Fig. 3.

The form of the beam from the reflector is altered by a spreader lens, the object of which is to modify the beam in such a way as to provide a suitable brightness distribution over the road when viewed from the driver's position. Invariably the design of this lens and, in fact, the design of the whole optical system depends on a compromise between the requirements of the meeting beam and the requirements of the main driving beam. A particular aspect of this question of compromise is the nearness with which each filament can be placed to the focus of the reflector. If the reflector accuracy is high it is desirable that the back of the meeting beam filament should be as near as possible to the focal point. At the same time the most satisfactory main beam will be obtained if the main filament is placed at the focal point itself. These requirements are clearly incompatible, and it is normal practice for the meeting beam filament to start a little in front of the focus and the main beam filament to be placed a little behind it. Sharpness of the horizontal cut-off depends on the general form of the reflector and, in particular, the form at its periphery. The most satisfactory form of main beam also depends on the accuracy of the reflector and choice of main beam filament shape. Quite considerable variations in main beam filament design exist as the result of various designers' solutions to the problem of providing a satisfactory main beam with a filament slightly displaced from the ideal position and with reflectors suffering from minor errors.

The hard horizontal cut-off of the meeting beam has been used as a feature for the aiming of the lamps in service, and because of the greater importance of the aiming of the meeting beam than the aiming of the main beam from the point of view of other road users, this simplicity of setting of the European type of beam has been stressed as a desirable feature. Fig 4 shows the intensity of a typical European headlamp and is, in fact, the beam distribution of the lamp taken as representative of European practice by the I.S.O./C.I.E. Working Party. It is evident that relief from glare will be obtained for approaching drivers at all points above the horizontal plane.

The intensity distribution below the horizontal shows that visibility distances at the road surface in excess of 100 ft. are very unlikely, and that in fact the road brightness will be falling off rapidly beyond 50 ft. Moreover, these limitations will apply along the nearside kerb as well as in other directions.

One of the most important results of adopting such a sytem is that by standardising the bulb construction to within close limits and thereby ensuring a consistent

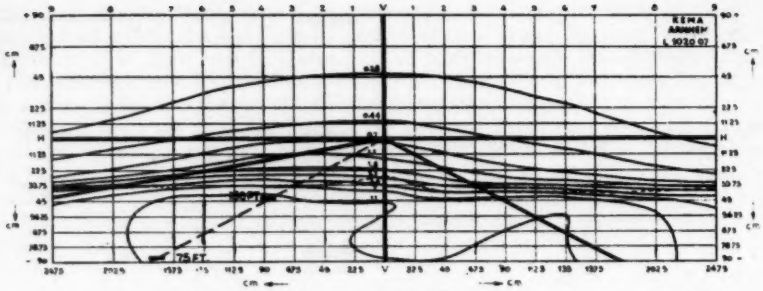

Fig. 4. Iso-candle diagram of European beam with road projection as seen by driver.

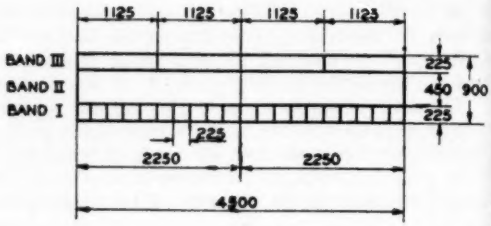

Fig. 5. European test screen. (Millimetres at 25 metres.)

product, a high degree of uniformity of the meeting beam is obtained even although the actual headlamp manufacturers' ideas may differ very considerably, and it must be freely admitted that uniformity of practice is one of the most important requirements for safety on the roads.

The control by European authorities has normally been by Government approval of sample lamps submitted by the manufacturer. For test purposes the beam is visualised as shining on a vertical screen at right angles to the axis of the lamp, and placed 25 metres from it. The screen is divided into three bands, as shown in Fig. 5, band 3 stretches effectively from the horizontal plane to 0.5 deg. below it, and the illumination in this zone is limited to 0.7 lux, thus leading to a maximum of 436 candelas at 0.5 deg. below the horizontal. Although this basic type of specification is applied in a number of European countries, notably France, Holland, Switzerland, Italy and Germany, there are in fact considerable differences between the different countries due to dissimilarities in test procedure, both as regards aiming of the beams and the voltage applied to the filament lamp.

Although this system is universal throughout Europe, enforced by government regulation in some countries and by convention in others, the attitude towards the problem of glare in the different countries is not quite uniform. Within Europe itself, it would probably be true to say that the Germans concern themselves far more with visibility, even at the expense of discomfort glare, while, at the other end of the scale, the French are convinced of the paramount importance of reducing discomfort glare, even at the expense of visibility. In searching for relief from discomfort glare and reduction in visual fatigue the French have, since 1937, made the use of yellow headlamps obligatory. The glass of the bulb is of a pale cadmium yellow, giving a very high transmission, but effectively removing the blue rays from the light. The claims made by French scientists for the use of yellow light are that it improves

visibility under conditions of glare and, even more importantly, it reduces fatigue under glare conditions.

Anglo-American Meeting Beam

The Anglo-American meeting beam differs in two respects from that used by the Europeans. In the first place, designers of this school do not use a hard horizontal cut-off, and although the beam intensity just above the horizontal is considerably less than that just below the horizontal, it is considered that sharpness of the cut-off is not in itself an essential feature of the well-designed beam. In fact, it is considered that the rate of change of intensity with angle should really depend upon two factors concerned with the use of the lamp in practice, namely the movement to which the beam will be subject in the vertical plane when the vehicle is travelling, and the errors(2) of aim prevalent in the country of use. The smaller these two variables become the sharper will be the desirable cut-off. Instead of choosing a symmetrical beam the Anglo-American designers select an asymmetrical distribution for their meeting beam. It is considered that as the oncoming driver is more likely to be to the offside of the vehicle and above the horizontal, it is more important that the meeting beam should give the driver visibility along his nearside kerb than that it should give relief from glare in this direction.

Studies of the actual conditions under which two vehicles meet are as yet by no means complete; those that have been carried out indicate that at a separation of 300 ft. an oncoming driver will occur 3 deg. to the offside of the nearside headlamp, and 2.4 deg. to the offside of an offside headlamp, with a standard deviation of 3.7 deg., and at the same time the oncoming driver will be 0.4 deg. above the horizontal with a standard deviation of 0.69 deg.

Fig. 6 shows the distribution of the positions of an oncoming driver's eyes, 3 deg. to the left and to the right for the forward direction, and in the case of a driver driving on the left-hand side of the road. The figures indicate that during the test period 24 oncoming drivers appeared in the zone 1—2 deg. up and 1—2 deg. right, whilst only seven appeared in the zone 0—1 deg. down and 1—2 deg. left. From this it will be quite evident that the importance of giving relief from glare in the upper offside quadrant is very much greater than to the nearside. A further factor, the full significance of which is not brought out by the diagram, lies in the fact that meeting in which the eyes of the oncoming driver occur in the nearside upper quadrant must inevitably be on bends, and the geometry of the meeting will be such that the oncoming driver's direction of view will be at a greater angle than average to the dazzling headlamps. Light, therefore, which is put near the horizontal to the nearside, and which enables a driver to position his vehicle accurately, will be relatively innocuous

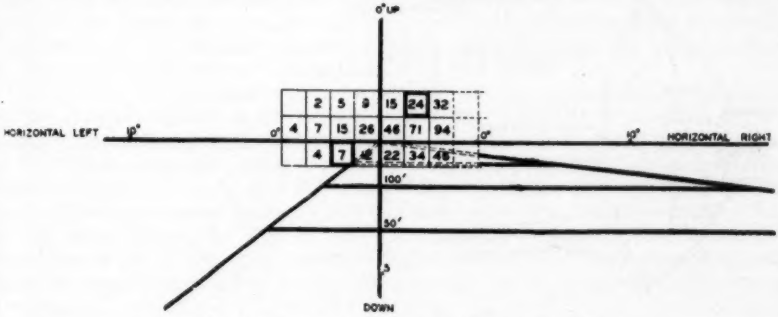

Fig. 6. Position of oncoming drivers at 300 ft.

from the oncoming driver's point of view, firstly, because of the relatively small number of drivers who meet it, and secondly, because those who do will be looking in such a direction that they will not be unduly inconvenienced by it.

In designing the optical system to give an asymmetrical beam of the Anglo-American type, designers have not used a filament shield of the form used in the European system. The principle of design, however, still requires an optical system which will give both main driving and meeting beam at will. Fig. 7 shows the optical system used in which two filaments are placed one above the other, the one on the focus giving the main driving beam and the one above the horizontal plane and displaced from the focal point giving the meeting beam. The diagram indicates how light from this displaced filament is deflected below the horizontal plane through the focus of the reflector, directly by reflection over part of the reflector area and by reflection by prisms over the remainder.

Due to the use of very compact filaments, the beam given by the reflector itself before passing through the lens is more concentrated than would be required for good lighting, both in horizontal and in vertical directions. The lens system, therefore, is made to spread and deflect the light both horizontally and vertically to yield the most suitable form of road brightness distribution. Although there is no optical cut-off as in the case of the European beam, there is effective separation between the meeting and main driving beams, and the component which is approximately equivalent to the European metal filament shield is in fact the lens system itself which, of course, is very much further from the filament. The design is, therefore, considerably less critical in this respect. The form of meeting beam given is shown in Fig. 8, from which it is evident that the glare intensity to the offside is somewhat above that given by the European close to the horizontal plane, but that the intensity below the horizontal is considerably greater, and the distribution is such that along the nearside kerb the driver has a greater visible range. It will also be evident from the diagram that aiming such a beam by optical means would be extremely difficult, and it is both British and American practice to aim lamps by means of the main driving beam.

Comparing the Two Systems

Designers working to these two schools of thought each claim superiority for their designs because of greater safety, better visibility, ease of setting giving greater relief from glare and the importance of uniformity in each territory. Without experimentation

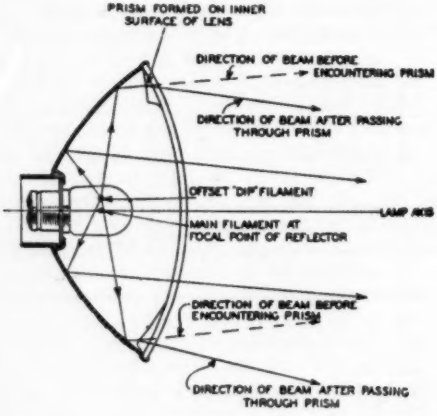
PRISM FORMED ON INNER SURFACE OF LENS
DIRECTION OF BEAM BEFORE ENCOUNTERING PRISM
DIRECTION OF BEAM AFTER PASSING THROUGH PRISM
OFFSET 'DIP' FILAMENT
LAMP AXIS
MAIN FILAMENT AT FOCAL POINT OF REFLECTOR
DIRECTION OF BEAM BEFORE ENCOUNTERING PRISM
DIRECTION OF BEAM AFTER PASSING THROUGH PRISM

Fig. 7. Anglo-American optical system.

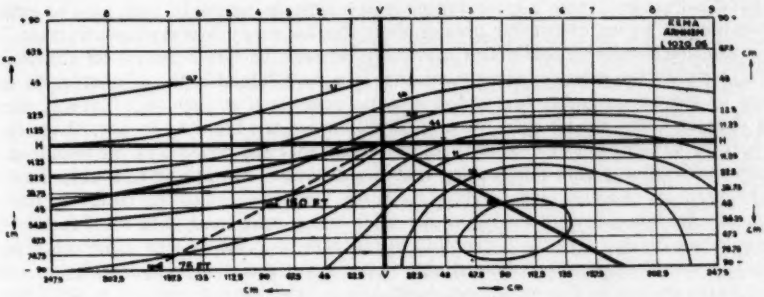

Fig. 8. American sealed beam iso-candle diagram and road projection as seen by the driver.

on a very large scale it is extremely difficult to examine at all scientifically the claims of the two schools, but perhaps the most important thing of all to realise is that both methods of design and manufacture to achieve the meeting beam for vehicles can be made to work satisfactorily. There is little doubt that with the great variety of headlamp manufacturers working to a number of different ideas for very different territories in Europe, there still remains a uniformity of pattern in the meeting beam which makes the product of France perfectly acceptable in Germany or Italy, and vice versa. In the same way, in the United States—particularly in the Inspecting States—with perhaps not such a great variety of manufacturers but with a very much larger number of vehicles and far higher traffic density conditions on the highways, there has also been steady improvement in the visibility conditions year by year.

The question of comparing the relative merits of the two systems was not, therefore, a matter of looking for very large differences, and because of this the importance of an effective method of assessing the meeting beam became a serious problem. In fact, this problem of assessment still remains, although a great deal of work has been done and comparison of the two systems is not now so haphazard as it was as recently as 1949. A further factor that complicated the start of the work of comparing the two systems was the lack of experience by exponents of one school with the practical use of the products of the other. This was primarily because most designers did their motoring in countries following the school of design in which they worked and so they had little chance of appreciating the road conditions elsewhere, and even where they had, the small number of places in the world where lamp setting is properly controlled is such that bad aiming of lamps may completely cloud the differences in design. For example, Belgium has a mixed population of vehicles with lamps of American and European types, but no serious examination of the problem could be made because of the variations in lamp setting, a situation which the Belgian authorities are improving as a result of the I.S.O. work.

As a basis of comparative tests, American opinion stressed the importance of visibility tests for objects on the straight road to the nearside. This was in no sense an attempt to say that only straight road conditions and nearside objects were important, but an attempt to choose a situation which provided experimental results approximately related to practice. A great deal of work was done during the development programme for the American Sealed Beam system, not only upon the visibility distance when meeting, but also upon the effect of test conditions on the drivers[3]. The European test procedures tended to use static tests to a far greater extent, it being claimed that with relatively simple experimental equipment a greater variety of seeing conditions can be examined.

Whilst both straight ahead visibility tests and static tests have their places in the

general assessment, there is great danger in allowing the results of such tests to influence beam design to an extent far greater than the necessary assumptions warrant. For example, the European Static Test inevitably favours the very hard cut-off at horizontal level, because far greater visibility distance can be attained with, of course, no undue glare to the oncoming driver, and it is quite possible that such tests have resulted in far sharper beam cut-off than moving conditions on the highway justify. Equally, the American straight ahead test, particularly using nearside objects, might well lead to a beam distribution giving satisfactory visibility distances, but failing to enable the driver to position his car sufficiently well. Of course, the designers of the lamps do not only depend upon such formal tests and are much more concerned with the "feel" of the beam when driving than with visibility distance measurements, but some work by the Road Research Laboratory showed how important it was that this general appreciation of a beam should be put on a more formal basis, and the test procedure developed by them particularly for the comparison of meeting beams[4], was one of the test procedures which were eventually adopted by the C.I.E./I.S.O. Working Party.

In this type of test two identically equipped vehicles are used and the drivers start from each end of the test track, meeting approximately in the middle. Obstacles are placed along the track so as to make the driving task difficult. To make a comparison between two lighting systems the drivers make a number of runs, using first one system and then another, the selection being made for the driver by an operator. The driver knows the lighting systems under test only by code names and is unaware of the system in use. He is only asked to answer the following questions:—

(1) Which of the two systems do you prefer without oncoming glare?
(2) Which of the two systems do you prefer with glare?
(3) Which is the less glaring system?
(4) Do you consider the differences between the systems large or small?
(5) Do you consider the glare experienced,
(a) negligible, (b) moderate, (c) glaring, (d) very glaring?

Organisation of the Tests

The first attempts by the I.S.O. to compare the European with the Anglo-American type of lighting took place at Zandvoort in 1949, when straight road testing was used and these results supplemented by static tests. The results of the tests were of very limited value as a comparison, but they were an essential preliminary to the later tests in that they brought out the very great importance, for international tests on such a scale, of laying down the test procedure with meticulous care. They also showed the differences associated with the aiming of lamps, a difficulty which even the Working Party report shows was not overcome completely in the later tests. It was because of the very wide scope of tests necessary that the I.S.O. asked the help of the C.I.E. in carrying out the programme, and it was for this reason that the Brussels Working Party (1952) was set up jointly by I.S.O. and C.I.E. to draw up the procedure for the tests and to carry them out.

The first problem for the Brussels Working Party was to arrive at agreed representative samples of the European lamp on the one hand and the Anglo-American lamp on the other. The intention was not to produce an ideal lamp of either school of thought but rather to select a lamp which was representative both of practice and of the mode of thought of the designer. Because, in the majority of countries taking part in the tests, drivers were accustomed to driving on the right-hand side of the road, the obvious solution for the Anglo-American school was to take the current American Sealed Beam Lamp. This was not at the time, nor it is now, meant to indicate agreement between British and American designers on a common specification. Table 1

gives the comparison between the meeting beam specifications of the S.M.M. & T. and the S.A.E., and shows quite considerable differences in detail, although the general form of the requirements is similar. Selection of a representative European lamp was a little more difficult and a European sub-committee was set up with the object of agreeing the particular criteria to be fulfilled by a lamp of the European school and to select a lamp giving a representative performance. The scope of the tests which was considered essential to make a worthwhile comparison made it quite impracticable to consider carrying out the complete programme, as had been done in Zandvoort, in one meeting of all the interested parties. It was therefore agreed to split the programme up and allocate to the National Committees the responsibility of organising selected tests within their own countries, and at the same time a sub-committee was formed with one representative from each delegation with the duty of examining the tests in each country, and ensuring that the test procedure used was as agreed by the full committee. Table 2 shows hows the programme was split up, the Netherlands taking all photometric tests, Germany, France and the United States undertaking visibility tests under various conditions, and Great Britain undertaking *general appreciation* tests under a variety of conditions.

Although the differences in aiming in no way affect the general conclusions drawn

Table 1

Comparison of S.M.M. & T. and S.A.E. Meeting Beam Standards

BRITISH S.M.M. & T. STANDARD One Lamp			AMERICAN S.A.E. STANDARD One Lamp		
Test Points*	Intensity (Cd)		Test Points*	Intensity (Cd)	
	Max.	Min.		Max.	Min.
½ U–4 R	600		1½ U–1 R to R	1,000	
1 R	1,000		1 U–1 L to L	500	
1 L	1,500		½ U–1 R to 3 R	2,000	
3 L	2,500		½ U–1 L to L	800	
H 4 R	1,000		½ D–1 R to R	10,000	
1 R	1,500		½ D–1 R or 2 R or 3 R		3,750
1 L	3,000		½ D–1 L to L	2,000	
3 L	4,000				
½ D–1 R	2,500				
1 D–1 2 3 L		5,000	1 D–1 L to 6 L		1,000
6 R		750	1½ D–1 R or 2 R or 3 R		10,000
6 L		2,500	1½ D–9 R and 9 L		750
1½ D–9 L and R		750	2 D–15 R and 15 L		500
2 D–1–4 L		10,000	4 D–4 R	12,500	
2 D–2 R		5,000			
2 D–6 R		1,500			
2 D–9 R		1,000			
2 D–6 L		2,500			
2 D–12 L		1,000			
2½ to 3½ D–12 L		750			
2½ to 3½ D–12 R		500			
4 D–2 L	20,000				

*Test points are indicated by degrees Right or Left and Up or Down.

Table 2

Distribution of Working Party Tests

Detail Tests	Carried out by	Place and Date of Performance	Test Conditions							
			Road		Aiming of head-lamps		Surface		Colour of the light	
			straight	curved	correct	incorrect	dry	wet	clear	yellow
Photo-metry	Holland	KEMA Arnhem Summer 1953								
Visibility Tests	Germany	Norisring near Nurnberg. Feb./Mar. 1954		X	X		X		X	
		Hockenheimring March 1954	X		X			X	X	
	France	Bois de Boulogne, Dec. 1953, Jan./Feb. 1954	X		X	X	X		X	X
	United States	Proving Ground General Motors Milford, June/ July 1954	X		X		X		X	
General Appreciation	Britain	London Airport, Dec. 1953	X	X	X	X	X	X	X	X

from the experimental results, it is important that they should be recorded as they must inevitably affect certain detail conclusions, since they show that in spite of the hard optical cut-off, which characterises the European meeting beam, uniformity of setting was for one reason or another not attained for European lamps in spite of the fact that designers of the European school were always present. At the same time no such difficulty arose throughout the whole series of tests in the case of the lamps of the Anglo-American school. Fig. 9 shows the slight angular differences in setting which were actually used during the tests in various countries. These, for example, show that in the straight road tests carried out in America, the setting of the European lamp which was carried out by representatives of the European school was, in fact, ½ deg. higher than the setting agreed according to the measurements by K.E.M.A.

The final column states the average aim in service and this is frankly not accepted by the author, who believes that a very large percentage of European lamps are set at least ½ deg. below this aim. In fact the supposed incompatibility of the two systems may well rest on such a difference between practice on the roads and practice under test conditions.

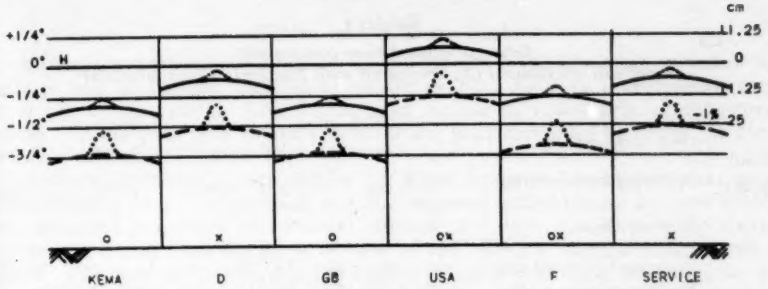

Fig. 9. Differences in aiming of European lamp during tests. (Screen at 25 metres).

o *Photometric aiming*
x *Visual aiming*
——— *Isolux 0.7 lx 300 lm*
- - - - *Visual cut-off*
—•—•— *Peak of isolux*
• • • • • *Peak of visual cut-off*

The representation of the "peak" is purely conventional the dimensions being out of proportion with the reality.

Results of the Tests

As might be expected, very nearly all the results showed relatively small differences between the two systems. In the case of the visibility distances, it was evident that the asymmetrical beam of the Anglo-American school gave superior visibility distances on the nearside and that the differences were significant; for objects in the centre of the road the differences were not significant, whilst for objects on the offside of the road the European beam gave significantly greater ranges of visibility. When meeting on a curve, a centrally placed object was better seen on a right-hand curve with the American system and on a left-hand curve with the European system, but in both cases the differences were relatively small.

The advantage of asymmetry in the nearside of the meeting beam is quite clearly brought out by the *visibility* tests and the recommendations for the new unified European meeting beam show that this fact is accepted, not only by the Anglo-American school, for whom this was a major feature for their design, but now by the European school, who had previously rejected it.

The significance of the improved visibility to the offside shown by the tests for the European school is not quite so clear. In the first place visibility distances of this type would be very susceptible to the angle of setting, about which, as has been pointed out, there was some considerable doubt. Secondly, the significance of such visibility distances, from the point of view of road safety, is problematical. At this point it is worth while stressing that this part of the tests was concerned with the visibility of obstacles not with the visibility of the highway itself, which is perhaps more nearly related to the results of the *general appreciation* tests.

The *general appreciation* test results comparing the lamp representative of the Anglo-American school with that of the European school are given in full in Table 3. The centre column of results gives the opinions stated by the observers when both lamps were correctly aimed. The results to the left show the effect of aiming the driver's own lamps down whilst the lamps for the oncoming driver were aimed high. This procedure was adopted so that the misaim in this direction should lead to the worst possible results, whilst to the right, the tables show the driver's own lamps aimed up with the opposing lamps aimed down, yielding for him the most favourable results.

For dry roads the most important result is really the very high proportion of observers who considered that the difference between the two systems was small. For

Table 3

General appreciation comparison
American uncoloured (A) compared with European uncoloured (B)

Road Surface	Own lamp setting / Opposing lamp setting	High glare						Low glare			
		− 1 deg. / + 1 deg.		− ½ deg. / + ½ deg.		correct / correct		+ ½ deg. / − ½ deg.		+ 1 deg. / − 1 deg.	
	Meeting Beam	A	B	A	B	A	B	A	B	A	B
Dry	Preference without glare	15	6	14½	5½	11½	8½	11	9	8½	11½
	Preference with glare	16	4	13½	6½	11	9	7½	12½	8	12
	The less glaring system	15	5	12	8	10	10	8½	11½	9	11
	Proportion*	18/20		17/20		19/20		19/20		19/20	
	Glare assessment. negligible	5	1	7	5	7	8	8	11	13	15
	Glare assessment. moderate	6	7	7	7	6	8	9	5	7	4
	Glare assessment. glaring	7	9	3	4	6	3	1	3	0	0
	Glare assessment. very glaring	2	3	2	3	0	1	1	0	0	0
Wet	Preference without glare	16	4			13	7			9½	10½
	Preference with glare	15	5			11½	8½			10½	9½
	The less glaring system	15	5			12	8			8½	11½
	Proportion*	15/20				19/20				19/20	
	Glare assessment negligible	3	1			6	2			7	7
	Glare assessment moderate	7	3			7	10			8	10
	Glare assessment glaring	10	10			6	4			5	2
	Glare assessment very glaring	0	6			2	3			0	1

* Proportion of observers judging difference in glare between A and B small.

conditions of high glare, that is one's own lamps set low and the other lamps set up, the preferences in favour of the Anglo-American lamps were significant, and it is worth noting that an error in setting of 1 deg., although very large from the point of view of the designer, is quite common in this country, and in fact over 50 per cent. of the cars even with built-in headlamps exceeded this in a survey taken in 1952 and reported on by the Road Research Laboratory(5).

When the road was wet the proportion of observers considering the differences were small was not so high and the general trend of opinion was more strongly in favour of the Anglo-American system. It is significant throughout that under the controlled conditions most test observers generally considered the Anglo-American system the less glaring system, but even when the European lamp was considered less glaring, the American lamp was preferred. It was also significant that under conditions of high glare, when the lamps were set up, the preference in favour of the American lamp was significant and the observers considered that the difference in glare was noticeable.

If these tests were really carried out under conditions representing usage in Europe and America it is difficult to reconcile the results with the complaints in Europe of the glare from American headlamps. It is for this reason that the author believes that European lamps are normally aimed much lower than in the tests.

White and Yellow Light

Among the most discussed matters on car lighting is the advantage of yellow light, and it is well known that the French authorities, as a result of investigations carried out in French laboratories, have standardised the use of yellow light as obligatory in France. At the same time no other country has been persuaded to accept the French resolution entirely.

Recent experiments carried out by the Road Research Laboratory, some as part of the Working Party's programme and also reported independently by Jehu (1954)[6], have compared yellow and white beams of identical distribution, both by the appreciation technique and from the point of view of the visibility distance obtained for test objects. The tests on visibility in the absence of glare and using beams of the same intensity regardless of colour, showed a very slight preference in favour of yellow light. As this is not a practical situation and it is only possible to obtain yellow light for headlamps by means of filters, the correction for the filter considerably reduces the small difference in visibility distance and the conclusion is that there is no significant difference between them. Individual drivers might, however, find one or the other colour preferable. Under conditions of glare the differences were slightly greater but even these, when corrected for the inevitable loss due to the yellow filter, were not

Table 4

General Appreciation Comparison

European Uncoloured (A) Compared with European Yellow (B)

Road Surface		High glare						Low glare			
	Own lamp setting	− 1 deg.		− ½ deg.		correct		+ ½ deg.		+ 1 deg.	
	Opposing lamp setting	+ 1 deg.		+ ½ deg.		correct		− ½ deg.		− 1 deg.	
	Meeting Beam	A	B	A	B	A	B	A	B	A	B
Dry	Preference without glare	18	2	16	4	18	2	18½	1½	18	2
	Preference with glare	11	9	12½	7½	12½	7½	13	7	13½	6½
	The less glaring system	9	11	7½	12½	6½	13½	8	12	9½	10½
	Proportion*	20/20		20/20		20/20		20/20		20/20	
	Glare assessment negligible	2	3	7	8	8	7	10	12	18	19
	Glare assessment moderate	9	8	7	6	10	10	10	8	2	1
	Glare assessment glaring	5	7	5	6	2	3	0	0	0	0
	Glare assessment very glaring	4	2	1	0	0	0	0	0	0	0
Wet	Preference without glare	19	1			17½	2½			19½	½
	Preference with glare	10	10			12	8			9½	10½
	The less glaring system	7	13			8	12			9½	10½
	Proportion*	20/20				20/20				20/20	
	Glare assessment negligible	0	0			2	2			3	3
	Glare assessment moderate	5	5			5	6			8	10
	Glare assessment glaring	8	9			11	9			9	7
	Glare assessment very glaring	7	6			2	3			0	0

* Proportion of observers judging difference in glare between A and B small.

sufficient for a recommendation for one colour or the other to be made. It is, however, possible to say categorically that no great improvement in visibility distance is obtainable by the use of yellow filters.

The *general appreciation* tests, Table 4, were a little more definite in their results. Drivers on the whole stated that when driving with yellow lamps and meeting identical yellow lamps, they experienced less glare than when driving with white lamps and meeting white lamps, but they quite definitely stated that they preferred to drive with white lamps. It would appear, therefore, that under the severe conditions of *general appreciation* tests, when the driver is not in a position to be introspective, his judgment will be on the quality of the lighting system as a whole rather than on some individual attribute of it.

Recommendations of the Working Party

The recommendations of the report as forwarded by the I.S.O. to the Economic Commission for Europe are worth quoting verbatim.

"The recommendations appearing in this report may be subject to frequent changes to keep pace with technical advances. Their inclusion in legal texts, where flexibility of revision is lacking, is therefore discouraged.

(1) *Aiming*

For good performance of a passing beam correct aiming is essential and it is recommended that the headlamp aiming in service be inspected periodically.

(2) *Light Distribution*

At the present stage of the art, to obtain a better visibility along the right edge of the road, which is required to promote safety, it is necessary to accept a certain asymmetry of the passing beam. (An asymmetric beam developed for one rule of the road should not be used in countries with the opposite rule of the road.)

The Anglo-American delegations recommend in principle the passing beam covered in the current (1955) S.A.E. Handbook for the improved Sealed Beam with asymmetry appropriate for the rule of the road to which it applies, and that it be adopted as an international standard.

The European delegations, except Belgium*, recommend in principle the uniform European passing beam as covered in Annex V, with asymmetry appropriate for the rule of the road to which it applies and that it be adopted as an international standard.

The delegations recommend that passing beam specifications be based only on the luminous characteristics to the exclusion of any power limit.

(3) *International Approval*

It is recommended that countries accepting a same specification of passing beam should come to an agreement to accept on a reciprocal basis the use of headlamps approved by one of them according to this definition, and to a unique approval procedure tied to this definition.

(4) *Interchangeability*

As it appears that different headlamp units (see Draft Recommendation I.S.O. No. 38) will be the answer to the respective recommendations of the Anglo-American and the European delegations ISO/TC 22, in view of providing relief to existing conditions, has studied overall and mounting dimensions which will allow mechanical interchangeability between the various systems.

It is evident from the second and fourth recommendations that whilst the Working Party members do not see the possibility of a single standard of performance for the

* The Belgian delegation accepts in principle both European and Anglo-American beams.

headlamp meeting beam, firstly for the fundamental reason that with an asymmetrical meeting beam a common product for the left and right hand rule of the road is not possible, and secondly because so far European and American ideas, although now agreeing on the use of an asymmetrical beam, cannot be satisfied by a common specification. Any suggestion that because of this no progress at all has been made would merely show a lack of understanding of what has, in fact, taken place in Europe itself.

Although there was a European system in the loosest term when the Working Party started and although the differences in specification were not large, they were considerably enhanced by differences in test technique. The new unified European system which is recommended will, in fact, completely remove all these differences and the specification will inevitably lead to a greatly reduced variation in European headlighting.

The fourth recommendation recognises the commercial importance of making it possible to fit lamps of the appropriate school of thought on to all vehicles which are made for sale throughout the world.

By far the most important recommendations however, are the first and third, both of which clearly indicate a unanimity of opinion between designers of the different schools of thought. Throughout the whole series of tests it was perfectly obvious that good seeing conditions, and therefore adequate road safety, were only obtainable in traffic if the lamps were not only designed and manufactured correctly, but were maintained and used correctly. The recommendation, therefore, that the headlamp aiming in service should be inspected periodically means not only the acceptance of, but the demand for, vehicle inspection. The third recommendation of International Approval makes the assumption that as safety equipment, the headlamps used in a territory have to be approved by the authorities. This, of course, is the case for most of the countries whose delegations took part in this work, to whom of course international acceptance of approval becomes important.

Conclusions

The immediate practical result of the Working Party's report is, of course, the New Unified European beam. Even if this still differs from the ideas of the Anglo-American school, it represents an advance in two respects, firstly there is now one agreed standard for Europe, and secondly, the differences between the European and Anglo-American ideas have been reduced.

The overwhelming importance of lamp aiming is made quite evident and the clear call for vehicle inspection must also rank as a major practical result of the report.

On the more theoretical side the new methods of assessment, although their development is not yet complete, have already improved our understanding of the factors involved in vehicle lighting. Among these is the influence of the lamp aiming standard in a territory on the design of meeting beam most suitable, a factor stressed by the work of the Road Research Laboratory.

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Discussion

MR. G. GRIME: As secretary of the National Illumination Committee Sub-Committee concerned in the ISO-CIE tests described in the paper, I have been associated with Dr. Nelson throughout the course of this work, and I am therefore particularly pleased to be asked to open the discussion.

Before commenting on technical aspects of the international tests, however, I wish to pay tribute to the part which Dr. Nelson has personally played in making the trials successful. It is no exaggeration to say that his influence has been of vital importance in ensuring a positive outcome and in reconciling the often conflicting points of view of two continents.

Dr. Nelson has pointed out the valuable results which have come out of the ISO-CIE tests. The Brussels Working Party is a most successful example of international co-operation, and it has shown that useful investigations on problems of common interest can be made by co-operative effort in a number of different countries. Full agreement was obtained on two important points: (1) that an asymmetrical beam was better than a symmetrical one, and (2) that good aiming of the passing beam is essential, and that aim should be controlled by inspection. In addition three standard beams were adopted for use in the three principal areas, Europe, America and Britain. There remains, however, insufficient appreciation in other countries of a point which has been emphasized frequently by the British members of the Working Party—that the design and usage of the meeting beam cannot be considered separately. For example, the better the aiming of headlamps, the sharper the cut-off which can with advantage be used. In this country, where many surveys of the aim of lamps on the road have been made, we know that there is little to be gained at present from sharper cut-off. In the United States, the converse may be true. From continental Europe, no measurements are available, at a time when they are most needed. A new European beam is being introduced, and to determine the value of this beam, it is essential to find out how it is being used, in terms of aim, by the general public. I hope that we shall be able to persuade our European colleagues to obtain data of this kind, and also that we may be able to get similar information for the American beam.

MR. J. B. DE BOER: As a member of the Brussels Working Party and having followed in detail the international tests on car-lighting, I am glad of the opportunity to join in this discussion. In the first place, I would like to congratulate Dr. Nelson on the very complete and clear information he has given on the subject.

As an exponent of the European school of thought, if I may so express it, I would like to stress, a little more than Dr. Nelson has done, the difference in glare caused by the headlights put forward by the different schools.

From Dr. Nelson's belief that the European lamps are normally aimed much lower than they should be according to the prevailing regulations, you may have got the impression that even if some difference in glare between headlights of the two schools does indeed exist, this difference is mainly causd by some continental habit of mis-aiming one's headlights. This is definitely not so, as I can show you by reference to the results of recordings made of the glare intensities of some 400 cars under normal driving conditions in my country. These results reveal that the average value of the luminous intensity of European headlights directed towards the eyes of an oncoming driver, is one third of the corresponding value for American Sealed Beam lamps. This ratio of 1 to 3 in corresponding glare intensities of European and Anglo-American headlights is very well confirmed by a comparison of the beam distribution curves measured on correctly aimed headlights of both schools.

I think it is very important to realise that this big difference exists, especially since now that the European experts have taken the first big step towards international

standardisation by accepting the asymmetrical passing beam, it is in fact the only fundamental difference left between the two schools of thought. A second big step, by removing the difference in glare levels, would contribute greatly towards complete international standardisation.

The demand for greater visual comfort in driving expressed by European experts, means less tolerance in admitting glare, which again means prescribing a greater rate of change of luminous intensity with angle just below the horizontal plane, the latter resulting in a sharp cut-off of the beam. Dr. Nelson has explained that the Anglo-American experts object to too sharp a cut-off because of the up and down movements of the beams during driving and of the prevailing errors of aim.

Now, in the first place modern car construction has improved the springing action to a great extent. Secondly, special devices for automatic control of headlight aiming are becoming available. These developments will no doubt result in a considerable limitation of vertical movements of the light beams.

Dr. Nelson considers the international recognition of the importance of good aiming and of periodical inspection of this aiming as one of the most important results of the international tests. I agree entirely with him in this respect. This recognition will in the future no doubt result in a considerable decrease of aiming errors, the second objection against too sharp a cut-off.

With this in mind, and in order to keep discomfort glare in road traffic as far as possible within tolerable limits, I think it highly desirable that the second big step towards complete international standardisation in car-headlighting should be taken, this time by the Anglo-American experts, by accepting the European limit of glare.

MR. V. J. JEHU: I welcome this paper because it gives the background to the international tests, and puts on record the British viewpoint towards those tests. The author has also saved me the task of reporting the British contribution to the tests!

As Dr. Nelson has said, the significant result which emerged from the tests was the superiority of the asymmetrical beam over the symmetrical one in revealing the important near side object, this despite all the doubts about the settings of the European lamps in the visibility distance tests.

This fact has obviously been taken to heart by the Europeans, who are now producing asymmetrical beams, in which, however, the most obvious improvements are the width and the uniformity of road brightness achieved near the vehicle, properties of the beam which everyone can readily appreciate.

Judging by our experience with the lamps so far, the term "unified" is rather optimistic. At the Road Research Laboratory we have examined new French lamps and also German lamps with Dutch bulbs, and although the beam patterns look alike on a screen, the measured glaring intensities differ by a factor of 2:1 at distances less than 400 ft. In fact the more glaring lamps give almost the same illuminating and glaring intensities as the new American meeting beam. It would appear at the moment then that variations will still exist within the new European beam, and that they will be of the same order as the differences between the American and European beams.

I say American beam and not Anglo-American deliberately, because it seems likely that we are approaching a situation in which the American and asymmetrical European beams are capable of almost the same performance when they are correctly aimed, a performance which is markedly better than that of the British beam. The important qualification here is the phrase, *when they are correctly aimed.* If in practice the new European beam is aimed low, as Dr. Nelson suggests is the case with the symmetrical beam, the improved performance of the new beam will be lost.

On the subject of comparison between British and American beams, I should like to refer for a moment to the beam specifications given in Table 1, and put in a plea

for standardised test points. I know that the American beam is wider and has a sharper cut-off than the British beam, with higher glaring intensities towards the near side, but it is difficult to extract this information from Table 1.

Coming nearer home to the conditions on our roads at night, I should like to ask Dr. Nelson if it is intended that the block lens units fitted to commercial and public service vehicles should be used as double dippers?

In practice many of the near side lamps are aimed permanently high along the near side road verge, and the offside lamp is merely switched on and off. This arrangement is most unpleasant to face, particularly on bends.

MR. J. G. HOLMES: This audience probably takes greater care of headlights than most motorists. The older type of headlight—which is likely to be particularly familiar to lighting engineers—required individual focusing of each bulb as well as correct aiming of the headlight, and a selfish motorist might set the dipped beam rather high so as to get the best revealing power without causing unacceptable glare to the oncoming drivers. A principal justification of the double filament lamp is that the angle between the driving beam and the meeting beam is not capable of alteration, so that a headlight with a correctly aimed driving beam will usually give a correctly depressed meeting beam.

It is, however, a melancholy fact that most motorists are selfish with their lights, whilst some seem to take a sadistic pleasure in using "fog lamps" and "pass lamps" shining so high as to cause serious disability glare. The only way of controlling these various spotlights seems to be by specification and inspection, with some sort of restraining sanctions imposed by the licensing authority or the police.

The designing of the meeting beam is rendered much more difficult by the requirement that the driving beam must be accurately focused and of high intensity. I wonder whether it would be better to design the optical system so as to give the best possible meeting beam and to accept a driving beam of inferior intensity, perhaps supplemented by a "spotlight" which would be extinguished when the dip switch is operated.

Dr. Nelson has indicated that reasonably satisfactory visual conditions obtain when two Anglo-American beams approach each other or when two Continental beams approach each other—can he say whether the two systems are compatible or whether the user of a Continental beam is at a serious disadvantage when confronted by an approaching Anglo-American beam?

MR. A. G. PENNY: I am sure all British motorists will welcome an opportunity to try a headlight with a new design of passing beam. Perhaps, before it gets too complicated, the experts could agree upon the correct name; is it "passing," "meeting," "dipped" or "town" beam? Similarly could we not call the new design "continental" rather than "European." In view of the growing integration of interests as between the United Kingdom and the rest of Europe, it is surely undesirable to talk about a European market as one that excludes the United Kingdom.

I think the general feeling of motorists who have driven with the old continental design as well as the present British one is that it is better to be *behind* the British beam but in front of the continental type. Such a selfish solution cannot, of course, be adopted, and it will therefore be of great interest to see whether the new design provides the better visibility of the present British design with the reduced glare generally attainable with the old continental system.

The remarks of Dr. Nelson have emphasised the very critical requirements of passing beam design, and I should like to know why more attention has not been given to designing headlamps for this specific purpose. The present practice of trying to make one optical system serve two purposes (driving and passing) must surely result in a compromise in at least one case. In view of the critical requirements, I would

have thought that such a compromise was most undesirable. Car manufacturers seem to be very ready to put a multiplicity of lights on to modern cars; why are they reluctant to provide us with two sets of headlamps—one designed for driving and one for passing?

MR. R. PELERIN: Cannot the author influence car manufacturers to ensure that the adjusting screws on headlamps are accessible. Whilst the ball and socket joint used on the headlamp of the older car had many disadvantages, it was readily accessible. With the modern car, with its many trimmings and ornamentation, it is often necessary to remove a large part of the front of the car before the adjusting screws are revealed.

MR. A. G. BROWN: Dr. Nelson and several speakers in the discussion have emphasised the importance of correct headlight aiming and drawn attention to the fact that a very considerable proportion of headlights in use in this country are by no means correctly aimed.

It seems to me that whilst there is no legal requirement for comprehensive vehicle inspection in this country, the average motorist is very much more likely to try to attempt the job of headlight setting himself, generally with unsatisfactory results, rather than pay for this task to be undertaken at a garage, and I think a strong point in favour of the European headlighting system with its sharp cut-off is the relative simplicity by which headlights of this type can be correctly aimed by means of adjusting the light/dark boundary line on the horizontal plane.

Regarding future headlight development, numerous references have appeared recently in the technical and daily Press to the introduction in America of four-lamp headlighting systems, and I would be interested to hear from Dr. Nelson whether any similar system is envisaged for this country.

I would be interested to hear whether Dr. Nelson has any detailed information on this American development. It would seem that the most reasonable approach would be to have two lamps designed solely for the passing beam and the other two for the main beam, and I would be interested to hear whether in fact this is the intended arrangement.

MR. J. B. COLLINS: Have any visibility trials been carried out with dirty windscreens; the disability effect of glare from the oncoming headlight depends rather critically on windscreen cleanliness.

The stopping distance from a speed of 40 m.p.h. is given in the Highway Code as 120 ft. on a dry road, but the visibility distance quoted in the paper for the European meeting beam is 100 ft. In view of the increase in driving speeds and in particular the high speeds common on the Continent, I wonder whether it should not be recognised that the meeting headlight beam is more a navigational aid than a means of determining whether the road is clear. I admit, however, that even if objects are revealed at distances less than the stopping distance, they can sometimes be dodged.

MR. J. W. T. WRIGHT: All headlamp bulbs are made at certain manufacturing tolerances: were the bulbs used in the tests specially selected to ensure that the filaments (and shield in the case of the Continental lamps) were in their objective positions?

Would the author, or Mr. de Boer, care to comment on which of the two systems is more susceptible to filament (and/or shield) movement, brought about by shock or vibrations in service?

MR. A. W. GOSTT: There have already been several references to the use of headlamp bulbs in yellow glass and I have tried both yellow and clear bulb headlamps over

a reasonably long period. Whilst there is a noticeable reduction in glare and therefore from the on-coming driver's point of view a welcome improvement with the yellow bulbs, under certain conditions in wet weather clear bulbs seem to me to provide better results. Correct aiming is essential.

Mr. Penny has referred to the fact of being more irritable when night driving as one gets older. I would think that general fatigue at the end of the day and a possible change in the eye adaptation rate due to increasing age may have some bearing on this point.

MR. C. A. JONES: I note the importance that Dr. Nelson attaches to the correct aiming of headlights, but even if considerable care is taken to aim headlights correctly, on the average car the spring deflection caused by the addition of even one passenger would be sufficient to upset the accuracy of the aiming.

Can Dr. Nelson say whether anything is being done to make it possible for headlamps to maintain the accuracy of their aiming in spite of varying load conditions.

DR. R. G. HOPKINSON: Dr. Nelson refers to the controversy on the value of yellow light for headlamps, and records that as a result of laboratory studies, the French lighting authorities have for some time insisted on the use of yellow light. Work in England, however, both before the war at the National Physical Laboratory, and recently at the Road Research Laboratory, failed to demonstrate any convincing and significant advantage for yellow light. It is curious, to say the least, that this discrepancy in the results of carefully conducted laboratory studies should have arisen. Experience suggests that when such a lack of agreement occurs, investigation usually reveals that different things have been investigated. What are Dr. Nelson's comments on this matter?

In this connection, is the recent work of Ferguson and Stevens (Trans. Illum. Eng. Soc. 1956) relevant to the problem? This work showed that at very high luminances yellow (sodium discharge) light is appreciably less glaring for the same photometer luminance than is white light. Is this a virtue of its yellowness or its monochromaticity? Other work may have been done to demonstrate this point. It would certainly appear that the controversy has not been settled by recent work.

MR. J. B. DE BOER: I would like to refer to the remarks by Dr. Hopkinson concerning the colour of the light. We have carried out a number of tests in order to compare uncoloured incandescent light with yellow light when used for car lights. Although we did not find differences which can be expressed quantitatively in such concepts as visibility distance or revealing power, we did find some significant differences between the two kinds of light. In the first place, we found—the proof is given in a paper presented to the CIE congress at Zürich—that less discomfort glare is experienced under yellow light than under white light if all other conditions are equal. Furthermore, we found a somewhat smaller re-adaptation time at yellow light after the disappearing of the glare source. As suggested by our French colleagues, we are now carrying out a course of tests on the reaction time for objects which appear in the periphery of the visual field. Although these tests are not yet terminated, they seem to indicate that the reaction time for objects appearing at an angle of 20 deg. or so, with the normal direction of view, is a little shorter under yellow light than under incandescent uncoloured light.

MR. C. R. BICKNELL: In this discussion reference has been made to the eye's adaptability to yellow and "white" light and, in this connection, an experience I had in mid-winter a few years ago may be of interest.

On entering a large town, the main roads of which are lighted by sodium lamps,

I switched off my headlamps. I switched them on again as I approached the last street lamp on the exit road but, immediately after passing it, found I had lost all visibility and had to stop for several minutes before I had lost my monochromatic yellow adaptation sufficiently for it to be safe to proceed.

This was, I may add, the only occasion on which I have experienced this effect so acutely and I have only met one other who has done so, though in common with a number of other people I have had it in a lesser degree on other occasions.

MR. W. ROBINSON: I would like, at this late stage of the discussion, to draw a red herring across the track and ask Dr. Nelson whether it is likely that, in the forseeable future, the whole problem of meeting beams may be resolved by the general use of polarising filters?

I cannot tell Mr. Holmes all he wants to know about running amok on the Continent but I could speak with the authority of bitter experience on the subject of running amok on Continental roads with British asymmetric meeting beams not corrected for the Continental rule of the road.

THE AUTHOR (in reply): I thank Mr. Grime and Mr. de Boer for their kind comments. I am sure that those who assisted in the Working Party's experiments had a unique experience in international co-operation which will be of lasting value.

With regard to the question of aim, I did not mean to imply, as Mr. de Boer almost suggested, that a difference in aim is the sole difference between the European and Anglo-American schools. On the other hand, it is my opinion that in certain countries the habit of aiming the European beam very low tends to exaggerate these differences. I, of course, appreciate the danger of generalising about practice within Europe itself.

Mr. Jehu refers to the variability of aim and will appreciate that the restricted range given by the British beam is a feature solely dictated by the very high variability of aim on British roads, a condition which American designers do not have to meet. Mr. Jehu is quite right regarding the use of lamps by commercial vehicles, the manufacturers fit lamps to the same performance standards as those fitted to passenger cars, with the intention that they should be used by the drivers to see where they are going. Unfortunately, control of safety equipment is very lax and many extremely dangerous practices have grown up among commercial vehicle drivers.

From the engineering point of view, one cannot help agreeing with Mr. Holmes and Mr. Penny that the driving beam and meeting beam should be provided with separate optical systems. However, from the practical angle it is even more important to ensure the correct aiming of the meeting beam, and its association with the driving beam has been one way in which this has been achieved. Up to now, the provision of a separate lamp to give the meeting beam has invariably led to abuse on the roads, but it may be that the four-lamp headlamp system, which has just been introduced in the United States, and in which one unit provides the meeting beam without any design compromises and at the same time contributes a certain amount to the main driving beam, while the other unit supplements the first unit's main driving beam, may in fact be a practical solution to the difficulties.

The aiming of the four-lamp headlamp system depends upon the fact that with the glass units the direction of the beam can be associated with the mechanical features of the units so that headlamp aiming can be purely mechanical. Under American conditions, where vehicle inspection is the rule rather than the exception, there is considerable chance of such a system working, but it is open to abuse and one cannot help feeling that where vehicle inspection is not compulsory abuse is very likely to occur.

Mr. Pelerin suggests that external adjusting screws should be provided for headlamp aiming, which I think very reasonable, though certain stylists, at the moment,

seem to have a horror of external screws. It could, of course, be that a screw would be abused.

In common with many exponents of the European system, Mr. Brown states that the hard cut-off makes accurate headlamp aiming practicable. At first sight this should be so but tests carried out by ourselves and by the Road Research Laboratory, the latter with a number of different headlamp aiming appliances, do not appear to support this view. During the Working Party tests, as has been pointed out, it was the European lamps with which we experienced aiming difficulties and not those of the Anglo-American school.

In reply to Mr. Collins and Mr. Wright concerning the state of the windscreen and the form of bulbs which we used in the tests, as far as practicable the windscreens were kept scrupulously clean and bulbs made exactly on design were used. The purpose of the tests was comparative and even when all the features that we could control were closely controlled the plan, at one stage, called for 144 nights of testing, 72 of which would have to be dry and 72 wet, so it will be appreciated that considerable compromise had to be made.

With regard to the limited visibility given by not only the European meeting beam but all meeting beams, it is interesting to note that on the majoriy of American roadways a top speed limit of 50 miles per hour is applied and super-highways rarely permit more than 60. In high traffic density it is my opinion that, not only is it impractical to provide visibility for speeds in excess of this, but that in dense traffic, even in daytime, the ordinary drivers' reactions are such that speeds in excess of this would be extremely dangerous. It must be freely admitted that the visible range provided by any of the lighting systems at night is inadequate.

In asking whether the Anglo-American and European systems could be used in the same territory, Mr. Holmes has pinpointed one of the disagreements between the various exponents. They are used together in certain European countries, of which Belgium is an example, and although the differences between the systems are real, I must repeat, in answer to this question, my opinion that the variability of aiming exaggerates the differences that really exist.

In reply to Mr. Gostt's comment on the subject of yellow bulbs, so far we have never been able to convince ourselves of the advantage of a yellow bulb over a clear bulb in any of the tests we have done with our own test car, when the same beam is available in either yellow or white at choice.

The Road Research Laboratory results on this question, as applied to European beams, certainly did not indicate any reason for expecting very strong preferences. One must have a slight suspicion that the driver will inevitably prefer a device he has purchased and fitted himself, to one which was fitted for him by the manufacturer.

Mr. Jones has raised an extremely serious problem, namely the variability of the aim of headlamps due to the movement of the suspension. This fact is unfortunately sometimes used as an excuse why nobody should bother to aim headlamps at all. The final solution must inevitably be suspensions which do not allow the vehicle to tilt under varying loads, and these suspensions will be on certain cars and vehicles in the not too distant future. In my opinion the interim solutions based on suspension deflection are not likely to be of very great practical value, except on fleets of vehicles subject to very careful engineering control.

I think Dr. Hopkinson has pinpointed a very important feature of many disagreements concerning lighting matters, namely that two different things were in fact being measured. For the practical purpose of headlighting, I believe that at the moment the choice of colour between white and yellow is very secondary to the far more important problems we are faced with, namely the aiming of the beam, consistent production of the headlamp and its maintenance. The variations that take

place within these would certainly completely swamp any contribution that a change in colour could make. This is in no sense meant to indicate that the question is not of considerable academic importance, but it is certainly my opinion that tests carried out so far on vehicles have been nothing like sufficiently extensive for any dogmatic statement to be made.

Mr. Robinson raises the question of polarised light as if it were a solution which would make our technical and administrative problems easier. Without wishing to go into any discussion on the practicability of polarised lighting systems, it must be evident that with our almost complete absence of control of lighting on the roads of Great Britain, its introduction could only be effected by very serious upheaval in our legislation, and whilst I believe that such an introduction could be effected in the United States where control of vehicles is much more advanced, I believe that here we should have to go through the stage of control of the simple lighting system before we could attempt control of the more complex.

Measurements of Electrical Characteristics of Fluorescent Lamps

By W. R. BLEVIN, M.Sc.

Summary

The connection of electrical measuring instruments in circuit with a fluorescent lamp usually alters its electrical and photometric characteristics. The nature and magnitude of these effects have been studied and a new method is described for determining the characteristics which the lamp would have if there were no measuring instruments in circuit.

(1) Introduction

It is well known [1, 2] that the electrical and photometric properties of fluorescent lamps are altered when electrical instruments are switched into their circuits for the purpose of measurement. This frustrates the industrial photometrist who wishes to know the performance of lamps under normal operating conditions with no meters in circuit, and leads to disagreement between results obtained with different types of measuring instruments.

Some laboratories have used "restoration" techniques[1, 3, 4, 5, 6] to overcome these difficulties, while others have developed special electronic measuring instruments[2, 4, 7]. However, very little quantitative information concerning the effects of the measuring instruments has been published, though it is known that the changes in lamp performance occur for two reasons, firstly because the instruments themselves consume power, and secondly because they alter the voltage and current waveforms of the lamp.

The present paper analyses these two effects and describes measurements of the changes which occur in fluorescent lamp characteristics when non-reactive measuring instruments of various resistances are connected in circuit. The existing methods for determining the normal operating characteristics of lamps are reviewed and a new method employing conventional precision instruments is described. Although lamps used in this investigation have all been of the 4-ft. 40-watt hot-cathode type, analysis of the results shows that they should be applicable to a wide variety of fluorescent lamps.

(2) Power Consumption of Instruments

Errors arising directly through the power consumption of electrical meters in circuit may be readily avoided by increasing the total power dissipation in the circuit to compensate for the amount consumed by the meters. Since power is a scalar quantity, the addition may be calculated algebraically.

The situation is not quite so simple when readings of the lamp voltage or current are being corrected, as illustrated by the following example. Consider the circuit shown in Fig. 1 of a fluorescent lamp operated in series with a suitable choke from a sinusoidal power frequency voltage supply. Suppose that it is desired to measure the r.m.s. lamp voltage V_l when a current of r.m.s. value I_l is flowing through the lamp, and that for this purpose r.m.s. indicating instruments V and I have been connected in circuit as shown. Since a current I_v equal to V_l/R_v flows in parallel with the lamp current, R_v being the resistance of the voltmeter V, it is clear that for a lamp

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The manuscript of this paper was first received on October 31, 1956, and in final form on December 12, 1956.

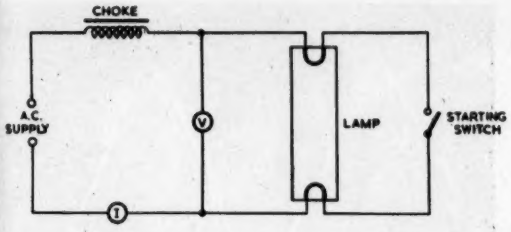

Fig. 1.

current I_l the supply voltage must be adjusted so that the ammeter registers a current somewhat larger than I_l. For highest accuracy the total current should not be calculated by algebraic summation of I_l and I_v as has sometimes been recommended[8], because these two currents have very different waveforms although they are in phase. It is well known that for a lamp operating in an inductive circuit from a power frequency A.C. supply the lamp current waveform is approximately sinusoidal, whereas the voltage waveform is approximately square (see Fig. 2). Assuming the waveforms of I_l and I_v to be perfectly sinusoidal and square respectively, the total r.m.s. current I flowing through the ammeter in Fig. 1 is given by

$$I^2 = \frac{\int_0^{\pi/\omega} (\sqrt{2}\, I_l \sin \omega t + I_v)^2 dt}{\int_0^{\pi/\omega} dt}$$

where ω is the angular frequency of the power supply. For the usual case where $I_v \ll I_l$ this equation reduces to

$$I \simeq I_l + 0.9\, I_v$$

Hence the value calculated by algebraic summation is too high by 0.1 I_v. In the case of an electrodynamic voltmeter, for example, this error may well amount to ½ or 1 per cent. of the lamp current, whilst in the case of an electrodynamic wattmeter, on the other hand, it is usually quite negligible. If the voltmeter is connected to the supply side, rather than the lamp side of the ammeter, similar corrections to the voltmeter reading are required.

The current drawn by instruments connected in parallel with a lamp and the voltage drop across series connected instruments may be computed provided that the impedances of the instruments are known. In practice it is usually more convenient to measure these quantites directly by switching an ammeter in series with parallel connected instruments and a voltmeter across any series connected instruments. This method does not require the provision of extra meters, as a suitable system of switches permits use of the meters already in circuit for measuring the lamp's characteristics. A wattmeter may be similarly used for measurement of the power consumption of any instrument.

(3) Waveform Changes

Even after allowing for the power consumption of meters connected in circuit with a fluorescent lamp, it is frequently found that the lamp still operates abnormally due to changes in its voltage and current waveforms. The nature of these waveform changes is now discussed.

The effect of parallel connected instruments is illustrated in Fig. 2 which shows the typical current and voltage waveforms of a 4-ft. 40-watt fluorescent lamp operated

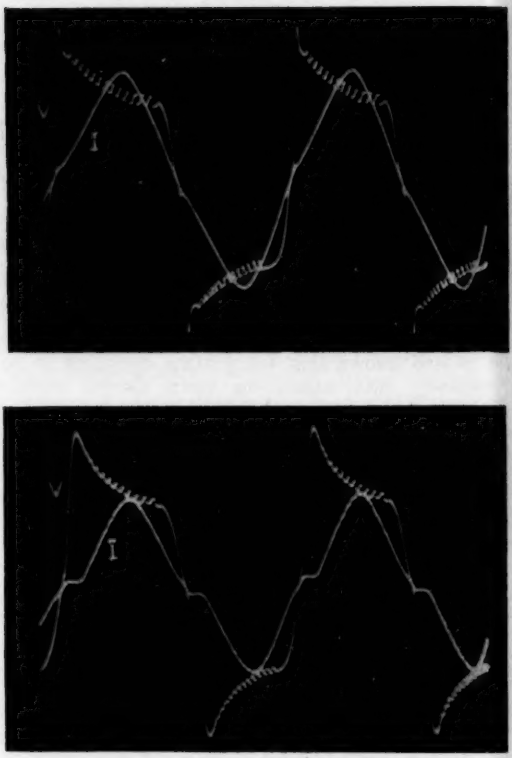

Fig. 2. Voltage and current waveforms of a 4-ft. 40-watt fluorescent lamp operated (a) normally and (b) shunted by a 1kΩ resistor.

in series with an appropriate choke from a 240 volt, 50 c/s sinusoidal voltage supply (a) normally and (b) with a 1kΩ resistance connected in parallel with the lamp. This low value of resistance has been chosen to accentuate the waveform changes. With higher values of resistance similar but less pronounced waveform changes occur. These observations agree with those of Fruhling and Marterstock[3] who have pointed out that the chief effect of the resistance is to lower the rate of voltage rise across the lamp at the beginning of each half-cycle, resulting in delayed re-ignition of the arc and a period of zero current. In the present case a small current is observed to flow prior to re-ignition of the arc due to the finite time required for the arc column to de-ionize.

These waveform changes can be accounted for theoretically as follows. Browne[9] has investigated the effect of shunting resistances on the initial rate of voltage rise each half-cycle for the case where the distributed capacitance in the circuit is negligible, and has shown that the voltage across the lamp at a time t after the current extinguishes is:

$$V_l = \frac{V_m}{1+\overline{L\omega^2}/R^2}\left\{\cos(\omega t-\theta)+\frac{L\omega}{R}\sin(\omega t-\theta)-\left[\cos\theta-\frac{L\omega}{R}\sin\theta+\frac{V_1}{V_m}\left(1+\frac{\overline{L\omega^2}}{R^2}\right)\right]e^{-Rt/L}\right\} \quad \ldots\ldots\ldots\ldots(1)$$

where V_m = peak supply voltage, L = circuit inductance, ω = angular frequency of

the supply voltage, R = circuit resistance during the re-ignition period, θ = phase angle by which current zero leads the peak supply voltage, and V_1 = lamp voltage immediately preceding the current zero. Fig. 2 shows that $V_1 \simeq 0$ in the present case and (1) may be rewritten as:—

$$V_l = V_m \sin \alpha \left[\sin(\omega t + \alpha - \theta) - e^{-Rt/L} \sin(\alpha - \theta) \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where α = arc tan $(R/L\,\omega)$. It is clear from (2) that V_l is oscillatory, and its amplitude approaches asymptotically a maximum value $V_m \sin \alpha$. For the arc to strike, the value of V_l must reach the re-ignition voltage, which itself increases somewhat with the time t. Connection of low impedance instruments in parallel with a fluorescent lamp may reduce α by such an extent that the lamp is prevented from striking(2).

Fig. 3 shows the rate of rise of lamp voltage calculated from (2) using numerical values approximating to the case of Fig. 2b; that is, $V_m = 240\sqrt{2}$V, L = 1.4 H, ω = 314 per sec., R = 1kΩ and θ = 30 deg. The lamp will not re-ignite until V_l reaches the re-ignition voltage, measured to be 170V in the present case. Fig. 3 shows that V_l takes a little over 1 millisecond to rise from zero to this value, during which time the only current flowing in the lamp will be due to cleaning up of ions and electrons left from the previous half-cycle. This computed time interval agrees satisfactorily in order of magnitude with the experimentally observed value of 1.3 milliseconds (see Fig. 2). However, this treatment should not be regarded as rigorous in its present application, for the characteristic of an iron-cored choke is not linear and the impedance of the lamp is not infinite during the re-ignition period.

It is seen from (2) that the initial rate of voltage rise across the lamp is:—

$$\left(\frac{dV_l}{dt}\right)_{t=0} = \frac{R}{L} V_m \cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Since θ is not very dependent on R, provided that the value of R is considerably larger than the lamp impedance, it may be concluded that for this case the initial rate of voltage rise is directly proportional to the resistance R. Hence low impedance instruments connected in parallel with the lamp lead to a low rate of rise and an

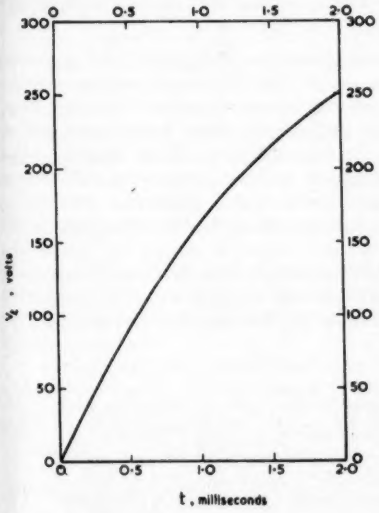

Fig. 3. Computed rate of rise during the re-ignition period of the voltage across a 4-ft. 40-watt fluorescent lamp shunted by a 1kΩ resistor. The arc re-ignites when the voltage reaches 170V.

appreciable time lag before re-ignition, this in turn leading to excessive de-ionization of the arc column and a lowering of the luminous efficiency of the lamp.

It may also be concluded from (3) that series connected instruments will not affect the initial rate of voltage rise appreciably, because their resistance is always very small relatively to the impedance of the lamp during re-ignition. In fact, observations show that series connected instruments have negligible effect on lamp waveforms. This may be understood by regarding the impedance of such instruments as part of the impedance of the voltage supply. Since the lamp current is approximately sinusoidal this additional impedance will not appreciably alter the sinusoidal waveform of the voltage supply.

It may be concluded then that whereas both series and parallel connected instruments in a fluorescent lamp circuit may consume appreciable power, only the parallel instruments alter the lamp's electrical waveforms.

(4) Existing Methods of Measurement

In view of the above analysis of the effects of measuring instruments in fluorescent lamp circuits, it is of interest to review briefly the shortcomings of conventional instruments and to discuss the adequacy of existing methods of overcoming them.

(4.1) Conventional Instruments

Conventional instruments whose deflection depends upon r.m.s values fall into four classes, viz. electrodynamic, electrostatic, moving iron and thermal instruments. Rectifier and electronic instruments do not usually indicate r.m.s. values of complex waveforms, though electronic instruments specially designed for this purpose are described in the following section.

Electrostatic voltmeters are the only conventional instruments which may always be used in fluorescent lamp circuits without necessitating special corrections. All other conventional instruments consume appreciable power and, in the case of voltage measuring elements, give rise to waveform distortion, though the situation has greatly improved with the recent advent of reflecting dynamometer meters of low power consumption. The use of electrostatic voltmeters in fluorescent lamp circuits is limited because of their fragility, instability and high cost.

(4.2) Thermionic Amplifiers

Some laboratories[2, 4, 7] have overcome the problems outlined in the preceding sections by using instruments with the impedance of the voltage measuring elements so high, and the impedance of the current measuring elements so low, that any interference with normal lamp behaviour is entirely negligible. These instruments consist of a precision dynamometer driven by very stable amplifiers which amplify small voltage and current signals with negligible change in phase or waveform. They may be used to measure lamp power, voltage and current and have the outstanding advantage that no correction is necessary for the presence of the instrument in the circuit

However, such instruments are not generally available and their use is not widespread although the technique was successfully applied as early as 1941[2]. This is probably due to the large amount of specialized work involved in their development and construction.

(4.3) "Restoration" Techniques

Various workers have adopted "restoration" techniques in order to correct for the presence of electrical measuring instruments in circuit. These techniques are based on an assumption that if one of the lamp parameters altered by the presence of instruments is restored to normal, then all the other lamp parameters will also be normal. The light output of the lamp has usually been chosen as the parameter to be

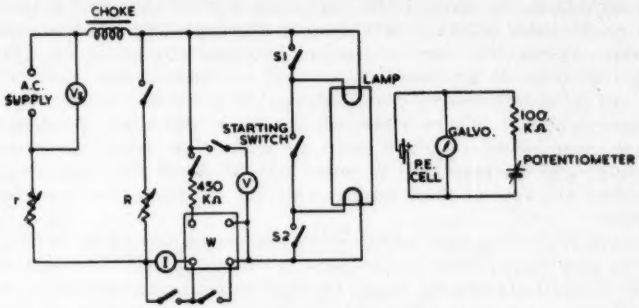

Fig. 4. Circuit used for measuring the effects of series and parallel connected resistances on the operating characteristics of fluorescent lamps.

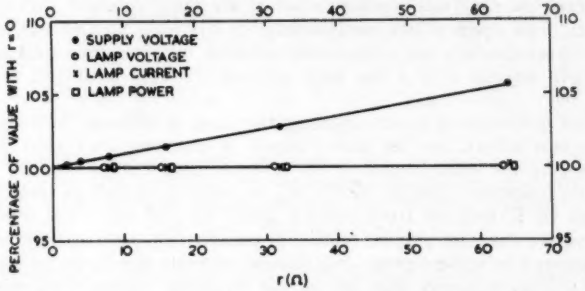

Fig. 5. The supply voltage required to maintain the light output of a fluorescent lamp constant, and the corresponding values of lamp voltage, current and power, as functions of the value r of a variable resistance connected in series with the lamp. Each quantity is plotted as a percentage of its value with r = o.

restored[1, 3, 4, 5] though Kapnik[6] has recommended restoration of the lamp current.

The "restoration of light" technique is used when the lamp parameters are to be measured at constant (usually rated) supply voltage. Basically the method consists of first noting the light output with the lamp operating normally and then, after inserting each electrical meter into circuit in turn, restoring the light output to its normal value by increasing the supply voltage before the meter is read. It is clear that such a technique would correct for the power consumption of the instruments if no change in the lamp current and voltage waveforms occurred, the extra power supplied to the circuit to restore the light output being equal to the power consumed by the instrument. Changes in waveform do occur in practice, however, and restoration of the lamp's light output does not fully restore its normal electrical characteristics. An experimental investigation of this limitation to the "restoration of light" technique is now described.

A 4-ft. 40-watt hot-cathode fluorescent lamp is connected in series with an appropriate choke to a sinusoidal 50 c/s variable voltage supply, as shown in Fig. 4. Variable resistors R and r and a dynamometer voltmeter V_s are connected in the circuit as shown. Electrical measuring instruments used to measure the lamp characteristics are a reflecting electrostatic voltmeter V, a reflecting dynamometer wattmeter W and a dynamometer ammeter I. The wattmeter voltage coil of resistance 50 kΩ is used in series with an external resistance of 450 kΩ so that its effective

resistance is 0.5 MΩ; the resistance of its current coil is 0.8 Ω while that of the ammeter is 6.6Ω. A photovoltaic cell fitted with a colour-correction filter and connected in a Campbell-Freeth circuit[10] is used to measure fractional changes in the light output of the lamp. In order to increase lamp stability all measurements are taken with switches S_1 and S_2 short-circuiting the filaments. The normal value of light output may be measured with R infinite, r zero, meters W, V and I out of circuit and the supply voltage set at 240.0V. When R and r are set to other values they divert power from the lamp, and consequently in order not to lower the lamp temperature significantly they are kept at these settings only for the minimum time required to read the meters.

The effect of connecting non-reactive series instruments of various resistances may be obtained by keeping R infinite and setting r to various values. For each value of r the meters W, V and I are inserted singly, the light output being restored to its normal value before the meter is read. Fig. 5 shows the fractional changes which occur in supply voltage V_s and lamp power W_l, voltage V_l and current I_l when r is varied from zero to values in the range 0—64 Ω. It is clear that in this case "restoration of light" has kept the electrical characteristics of the lamp constant regardless of the series resistance. This result is not unexpected as it has been pointed out in Section 3 that the lamp waveforms are not appreciably affected by low series resistances. The increase in supply voltage with r has been necessary simply to off-set the potential drop across r.

The effect of non-reactive meters shunting the lamp is obtained by keeping r zero, setting R to various values, and for each value of R inserting the meters W, V and I singly and restoring the light output to its normal value before reading the meter. Fig. 6 shows the fractional changes in V_s, W_l, V_l and I_l plotted in this case against 1/R, for values of R ranging from infinity down to 1.25 kΩ. The units for 1/R have been chosen so that the abscissa values approximately equal the current flowing through R, expressed in milliamperes; this follows because the lamp voltage is of the order of 100V. Fig. 6 shows that all of the electrical values vary with R even though the light output of the lamp is maintained constant. This is consistent with the discussion in Section 3, changes in the lamp's waveforms due to the presence of R having reduced lamp efficiency and made it necessary to increase the lamp current

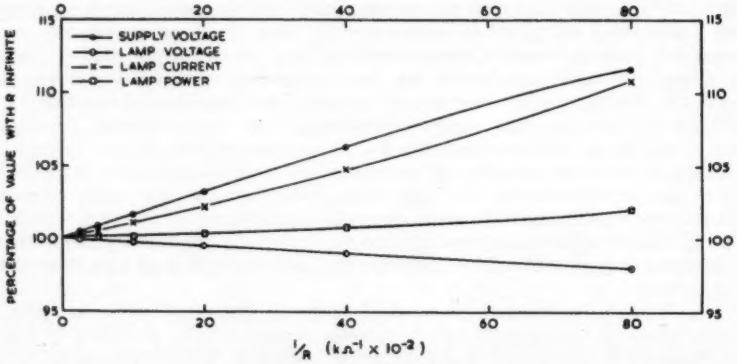

Fig. 6. The supply voltage required to maintain the light output of a fluorescent lamp constant, and the corresponding values of lamp voltage, current and power, as functions of the conductance 1/R of a variable resistance connected in parallel with the lamp. Each quantity is plotted as a percentage of its value with R infinite.

and power in order to maintain constant light output. As usual, the increase in lamp current has been accompanied by a decrease in lamp voltage.

These results show that restoration of normal light output fully corrects for the presence of instruments connected in series with the lamp, but only partially does so in the case of parallel connected instruments. Kapnik(6) has shown that his " restoration of lamp current " technique has similar limitations.

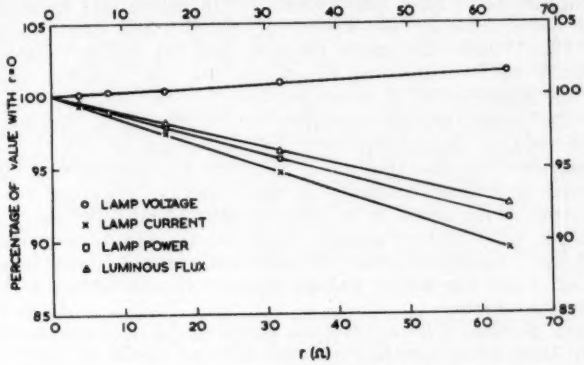

Fig. 7. The voltage, current, power consumption and light output of a fluorescent lamp as functions of the value r of a variable resistance connected in series with the lamp, the circuit supply voltage being maintained constant. Each quantity is plotted as a percentage of its value with r = o.

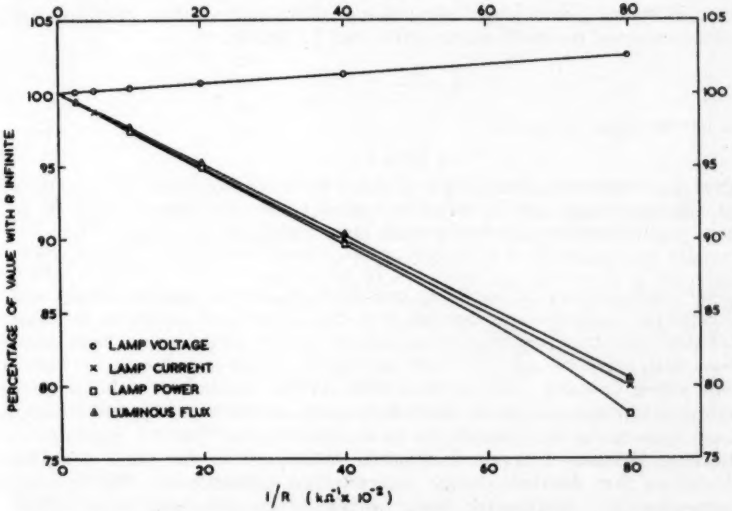

Fig. 8. The voltage, current, power consumption and light output of a fluorescent lamp as functions of the conductance 1/R of a variable resistance connected in parallel with the lamp, the circuit supply voltage being maintained constant. Each quantity is plotted as a percentage of its value with R infinite.

(5) Method of Extrapolation

One noteworthy feature of Figs. 5 and 6 is the close approximation of the curves to linearity, particularly for low values of the variables r and 1/R. The values of these variables have been extended well beyond those corresponding to actual high grade instruments, such as precision grade dynamometers, and even so the departures from linearity are not large.

Further measurements have been carried out to ensure that linear relationships also hold when one or other of the electrical parameters is held constant, instead of the light output. Fig. 7 shows the results obtained with the supply voltage maintained constant at 240.0V and r varied. It is apparent that the fractional changes in W_l, V_l and I_l and the luminous flux F are approximately linear functions of r. In Fig. 8, obtained with the supply voltage maintained at 240.0V and R varying, the curves again approach linearity, particularly over the lower range of 1/R.

Similar measurements have been taken next with the lamp power, and then with the lamp current, maintained constant. In each case the fractional changes in the other lamp parameters are found to be approximately linear functions of r and 1/R. The supply voltage V_s is the only quantity found to vary with r, again indicating that the presence of series instruments does not significantly alter the mode of operation of the lamp provided that the supply voltage is raised to compensate for the voltage drop across the instruments.

The practical problem is to ascertain the electrical and photometric characteristics of a fluorescent lamp when operating normally with no meters in circuit. The close approach to linearity of the curves discussed in this and the preceding section shows that the value of each parameter under normal operating conditions (r=o and 1/R=o) can be obtained by extrapolation if two points are known in the linear portion of each relevant curve. In particular, if an ammeter of resistance r_1 reads I_1 when connected normally and I_2 when connected in circuit in series with an external resistance of value r_2, then linear extrapolation shows that an ideal instrument of zero resistance connected normally would have read I_o, where

$$I_o = I_1 - (I_2 - I_1)\frac{r_1}{r_2}.$$

If r_2 is chosen equal to r_1, then

$$I_o = 2I_1 - I_2$$

Similarly, if a voltmeter of resistance R reads V_1 when connected in parallel with a lamp in the usual way, and V_2 when an external resistance also of value R is connected in parallel with it, then the normal lamp voltage is V_o where

$$V_o = 2V_1 - V_2.$$

Wattmeter readings may be similarly corrected by taking readings firstly with the meter connected normally, and secondly with the current coil connected in series with an equivalent resistance and the voltage coil in parallel with its equivalent resistance.

These extrapolations are only valid for meters whose impedances lie well within the range giving linearity. No problem arises in the selection of suitable ammeters and wattmeters; precision grade electrodynamic instruments meet the requirements easily and corrections are possible to an accuracy better than 0.1 per cent. of the total reading. Pointer type electrodynamic voltmeters on the other hand have a lower resistance than desirable though meters with a resistance of 6 kΩ on a 120-volt range are available. Fortunately lamp voltage is the parameter least affected by instruments in circuit (see Figs. 5 to 8) and in practice the corrections to be made are always small. Hence small departures from linearity cause negligible error, for example it was found experimentally to be less than 0.1 per cent. for a meter of resistance 6 kΩ. One necessary precaution with such an instrument is to connect it

in circuit only for the minimum time required for each reading, in order to avoid diverting power from the lamp for a prolonged period and hence lowering its temperature. This is specially the case when the *supply voltage* is being maintained constant; as an example of this case Fig. 8 shows that the power consumption of a 40-watt lamp is reduced by about 4 per cent. when the lamp is shunted by a voltmeter of resistance 6 kΩ and 8 per cent. when an equivalent resistance is connected across the meter. The change in lamp power consumption is considerably smaller, however, when one of the *lamp* characteristics is being maintained constant. For example, when the current of a 40-watt lamp is held constant, connection of a meter of 6 kΩ resistance across the lamp decreases its power consumption by only about 1 per cent.

Six 4-ft. 40-watt fluorescent lamps have been used during the present investigation, each giving results very similar to those described. Although measurements on other types of fluorescent lamps have not been undertaken, similar relationships are expected to hold for any tubular fluorescent lamp provided its electrical impedance is not considerably greater than those of the lamps investigated. Impedances of various tubular hot-cathode lamps operating on a 50 c/s A.C. supply have been computed from nominal voltages and currents tabulated by Anderson[11]. The impedance values listed in Table 1 indicate that all these lamp types would be affected in the same way by

Table 1

Nominal electrical impedance of various tubular hot-cathode fluorescent lamps operating on 50 c/s A.C.

Lamp Power (watts)	Length (in.)	Diameter (in.)	Impedance (ohms)
8	12	$\frac{5}{8}$	318
14	15	$1\frac{1}{2}$	105
15	18	1	175
20	24	$1\frac{1}{2}$	177
30	36	1	294
40	24	$1\frac{1}{2}$	59
40	48	$1\frac{1}{2}$	263
80	60	$1\frac{1}{2}$	125
125	96	$1\frac{1}{2}$	200

measuring instruments as the 4-ft. 40-watt lamps used in the present investigation. For lamps of higher impedance, such as the cold-cathode type, linearity might well break down in the case of parallel resistances at smaller values of 1/R.

The only comparable measurements described in the literature are those of Kapnik[6] who measured the changes in the light output and current of a fluorescent lamp when various shunting resistances were connected across it; analysis of his work shows that it agrees with the present results in that the fractional changes observed were inversely proportional to the value of the shunting resistance.

Conclusions

1. Most conventional electrical measuring instruments affect the operating conditions of fluorescent lamp circuits in which they are connected because of their power consumption and, in the case of instruments shunting the lamp, because of their effect on the lamp's voltage and current waveforms.
2. "Restoration" methods may correct for the power consumed by the instruments, but do not make any allowance for waveform distortion. It follows that they can be quite accurate for series connected instruments but residual errors remain in the case of parallel connected instruments
3. A new extrapolation method corrects for the presence of instruments in circuit

to an accuracy better than 0.1 per cent. It must be remembered, however, that matter what method be used for making electrical measurements, inherent la instabilities and limitations in meter accuracy will in most cases introduce uncertaint appreciably greater than this.

Acknowledgments

The author wishes to acknowledge the assistance of Mr. D. B. Armitage of t Division of Electrotechnology, Miss M. C. Cunningham and Mr. R. H. Kennett making the measurements.

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Printed by ARGUS PRESS, Ltd., 8 & 10, Temple-avenue and Tudor-street, London, E.C.4, England.